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A PERSPECTIVE ON HEALTH AND SAFETY RISK ANALYSIS*

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Health and safety risks are compared with financial risks, and the differences pertinent for risk evaluation and management are described. Such differences arise from the equities of risk distribution, the multiple stakeholders in the decision process, the opportunities for risk diversification, the interpretation of social values relating to risk choices, and in the political objectives in the decision process. Health and safety regulators are faced with the problem of making decisions involving large scientific uncertainties, public perceptions at odds with professional perceptions, uncertain and conflicting public values expressed through the political process, and difficult judgments of equity when risk and benefit are borne by different groups. The effect of highly publicized risk controversies on such regulatory decisions is described.
(RISK MANAGEMENT; RISK ANALYSIS; HEALTH RISKS)

Introduction

Health and safety risks have been an expanding area of study for the last two decades, largely as a result of increasing public concern with environmental effects of industrial activities. Risk analyses attempt to disclose the relevant cause and effect relationships which give rise to health and safety risks, to describe their approximate magnitudes and their distributions, and to identify management opportunities for risk reduction. Risk analyses also include consideration of the societal evaluation of risk, and in this respect are concerned with interpreting public attitudes and values.

This paper provides a brief perspective on the evaluation and management of technological health risks and the difficulties involved. Because we assume that readers of *Management Science* are knowledgeable about financial risk decisions from an analytical or theoretical framework as well as from a practical viewpoint, we start with a comparison of financial and health risk decisions, and, whenever possible, we describe health risk management from an economic basis.

As we note below, there are both similarities and differences in the nature of financial and health risk decisions. There is a gray area in which health risks can be treated as direct financial risks or costs, as from liability or insurance. But for most health risks dealt with at a national level, we find key decision elements that are not generally controlling in financial risk decisions, as for example, judgments of distributional equity and the social values that enter or are revealed through a political decision process.

Health Assets vs. Financial Assets

The management of any risk involves the allocation of available resources for the prevention or mitigation of the foreseeable risks and their consequences. In support of this objective, health and financial risk analyses are similar. The risk management approaches also share the decision tension between greed and fear: greed to achieve the maximum of health or financial assets, and fear of loss due to unpredictable exogenous variables. Beyond these similarities, the risk analyses of health and financial matters differ—so much so that the decision-making processes are not transferable.

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The management of financial risks by the use of sophisticated analytical methods is commonplace in business, government, and by individuals. The concepts of expected value, risk aversion, and risk spreading (as through portfolio diversification or insurance) are routinely applied, as is the thesis that the objective in decision-making under uncertainty is to maximize expected utility (often operationally defined as the net return on investment). (See, for example, Howard et al. 1977.)

When national health and safety decisions are examined, one is struck by the differences. In brief, the theoretical methods of decision-making and detailed analysis that are widely accepted for financial risks are not applied to health and safety risk decision-making. Decisions are usually made judgmentally; values are rarely made explicit.

Consider the ultimate goal of decision-making. In the case of the financial assets of the firm or individual, the broad objective is to continually add to the existing resources, i.e., accumulate wealth. The range of potential outcomes is open-ended on the high side and has the loss of assets (bankruptcy) on the down side. In the case of health assets, our normal reference datum is simultaneously the ceiling of "good health," defined as physical and emotional well-being, and measured by the absence of detectable disease, physical malfunctions, or early death. And we have no health floor except death, or on a national basis, catastrophic events causing many deaths. As a result, decision-making in health matters has as an objective the achievement of normal "good health" by either preventing deductions from the norm or by taking remedial steps, if available, when such deductions occur. Thus, while successful decision-making in financial matters is evidenced by a measurable increase in assets, in the case of health, success is evidenced only by the absence of "deductions"—an absence which might or might not be the result of the decisions made.

Perhaps the most significant difference between financial and health assets is that the latter does not have a single unit of interchange among its assets, i.e., the equivalent of money. Health is not fungible—no portion can replace any other part (e.g., good digestion cannot substitute for bad lungs). Further, good health is not transferable from one person to another. Unlike financial assets, health is not tradeable, or marketable, or insurable. So-called health insurance does not replace a health loss; it contributes only to the cost of medical attention, and health losses can only occasionally be restored by such medical aid. Life insurance does not restore life; it merely endows survivors. (It is really death insurance.) Unlike financial assets, health cannot be stored in inventory, so liquidity in the financial sense is not available. Health cannot be bequeathed, therefore, the politicans haven't yet devised a means to tax it.

For the decision-maker, the absence of a known nominal value for health (as in the money value of financial assets) prevents the use of the usual business calculus of return on investment, tangible dividends, and cumulative growth, when the allocation of personal or national resources is being considered. Yet experience tells us that health is a valued resource to the individual, and common sense tells us that a healthier society is a national asset providing dividends in greater social productivity and individual happiness, both for the present and succeeding generations. So these clearly are benefits that justify the allocation of resources to improving health and safety. But health is multi-valued, and we have no accepted composite unit of measure to guide decisions quantitatively; and thus the door is wide open to value judgments by individuals, political bodies, and institutions in answering the question, "how safe is safe enough?"

The principal differences between financial and safety decisions are listed in Table 1. As noted on this table, safety decisions require difficult value judgments to convert decision factors to a common metric, i.e., balancing health risks against costs. Several

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TABLE 1

Financial Risk vs. Health and Safety Risk

Issues	Financial Risks	Health and Safety Risks
◦ Decision Objectives	Maximize profits.	Risk reduction through regulatory management.
◦ Decision-Makers	Firm's executives.	Regulatory bodies and government agencies.
◦ Nature of Choice	Voluntary choice of group at risk.	Involuntary public exposures. Stakeholders can participate in decision indirectly through political process.
◦ Risk-Benefit Comparison	Balance of benefits and risks described in monetary terms.	Risks and benefits have unlike units; death as an ultimate risk is tolerable only for very small probabilities.
◦ Risk Aversion Strategies	Diversification; insurance.	Mitigation, prevention, and resilience.
◦ Diversification	Many useful risk-spreading and diversification strategies.	Risks add; no application of diversification possible, except on national scale.
◦ Insurance	Can provide restoration. For firm, averages losses over time.	Does not restore loss; supports medical aid; endows survivors of individuals. For firms, converts health and safety liability into certain cost.
◦ Benefit and Risk Distribution	Benefits and costs all internalized and distributed to employees and stockholders.	Benefits distribution may be widely different from risk distribution.

other significant differences are also noted. First, in health decisions the distributions of risk and benefit are spread among many different groups, and often the critical difficulty is making a decision regarding equity, as when the issue is occupational or public risk versus private expenditure to reduce risk. Similarly, the assessment of risk versus benefit can be influenced by the geographic scale of the analysis. Taking uranium power as an example, the local issues involve the balance of plant accident risks against local benefits. On a national basis, the important issues are likely to be reduced oil imports and diffuse risks, as from waste handling. Perhaps indicating a recognition of the importance of distributional effects, several European countries now compensate nuclear power neighbors financially.

The financial strategy of reducing the probability of large losses through diversification is well known (even intuitively) by investors, but is unavailable for individual safety risks. On a national basis, health risks to the aggregate population are diversified by having a variety of independent service systems, such as for transportation, thus avoiding harm to the total population from a single risk. While it may be appropriate to spread one's wealth between a number of investments, it makes no sense for an individual to diversify safety risks, for example, by flying on some trips and driving on others. While wealth can be protected by dividing it into small pieces, each of which is independently at risk, health cannot be so divided. Similarly, insurance cannot compensate anyone for their loss of life, although it can provide protection from financial loss. But for decisions involving risks to one's own life, about the best one can do is to seek risk reductions by applying consistent benefit-risk or risk-risk control trade-offs. It is this nonrestorable character of human life that, in part, gives safety decisions their special character.

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Assessment and Evaluation

Risk is the possibility of loss or injury, and risk analysis refers to its study. It is helpful to try to separate risk analysis into two aspects: assessment, which deals with questions of fact concerning the level (or probability), distribution, and character of risk; and evaluation, in which the social significance of risk is explored. While in practice it is impossible to make a complete separation, this distinction is nonetheless useful principally for the boundary it defines between questions which can be addressed scientifically and questions involving political decisions. The separation assists disciplined thinking about risk and the role of risk assessment in a broader decision process.

To those experienced with the methods of decision analysis and with the expected utility theory taught in microeconomics, this distinction may seem obvious—even superficial. But the fact is that in the historical approach to health and safety management, facts and values have been addressed simultaneously in ways which prevent such a simple separation. For example, the traditional engineering approach to safety is through design safety factors (i.e. make the bridge or airplane wing strong enough to handle some multiple of the load it is likely to see in service). In this approach to safety decisions, neither the residual risk nor the cost of further risk reduction is explicitly addressed. The appropriate safety factor is judgmentally determined by technical experts, often through voluntary standard-setting groups. Values are further embedded in the technical analysis through the use of conservative analytical assumptions when exact calculations are not feasible. The combination of conservative estimates and judgmental safety factors has worked well for issues that have enjoyed low profiles and professional consensus (e.g. boiler codes). But for many current risk issues such as nuclear power or toxic chemicals, this approach is not now accepted by the public.

Risk Assessment

In some cases, the assessment of risk can be based on direct data, as, for example, with automobile risks. Similarly, information can come from verifiable experiments such as by testing equipment to failure. But often, and especially for current risk issues of national contention, risk estimates are based on a little data and many plausible relationships. One such relationship is that established by retrospective statistical studies of the relation between health and exposures to some agent, e.g., a food additive or pollutant. These epidemiological studies can demonstrate correlation, and in rare cases where the effect is large (as with cigarettes), causation is assumed. But often one is simply left with a suggestive correlation, and a hypothesized relation between exposure and risk. In reference to low-level chemical risks, Donald Kennedy, former commissioner of the Food and Drug Administration (1981), wrote: "I have yet to find an epidemiological study that could not be converted into a scientific/legal donnybrook; experts could provide testimony on both sides of the question." "For example, the largest epidemiological study available to evaluate the risk of artificial sweetener use in bladder cancer involved half the cases of bladder cancer in Canada over a five-year period, yet it was a hundredfold too insensitive for regulatory purposes."

Another source of plausible relationships is through toxicological experiments, usually involving laboratory animals at doses much higher than those of interest for human risk estimation. While such experiments are generally reliable for identifying the nature of a risk, significant uncertainty surrounds the use of such experiments to provide quantitative estimates of human health risks from much lower doses.

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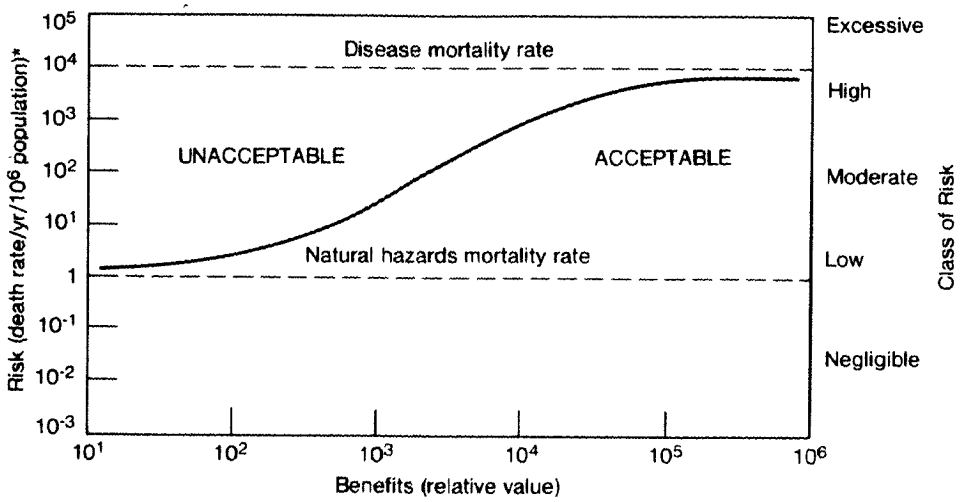
In the absence of actuarial information for full engineered systems, risk estimates can be developed through the technique of probabilistic risk assessment. In this approach, an analysis of system interactions is developed, and estimates or data on the behavior of subsystems is used to estimate overall system risks. This approach has been used for nuclear power plants, chemical plants, and commercial aircraft. Its success and validity depend strongly on the ability of the analyst; there is no standard procedure that one can follow to get the "right" answer. All these "plausible relationship" approaches share a common problem: their results are highly uncertain, and usually subject to challenge on a number of technical grounds.

Risk Evaluation and Management

The other half of risk analysis has as its objectives the management of risk. Once the magnitude and distribution of risk is known (to within uncertainty bounds), there are a number of obvious questions, such as: Is it acceptable? Is it worth reducing? Is it fairly distributed? These questions, while not technical or scientific in nature, can benefit from technical and economic inputs and insights. But at their core, these are political questions, with answers determined by political consensus. Risk management involves institutions to formulate or infer values, and to implement policies consistent with both values and risks, as perceived by those institutions. Risk evaluation and management can benefit from comparative analysis; it is often illuminating, when examining a particular issue such as a trade-off between safety and cost, to know what policy has been implemented in other similar cases, what implicit values underlie such policies, and the comparative success of management approaches.

On approach to risk evaluation is to assume that society has historically arrived at an acceptable balance between risks and benefits through an iterative process of trial and error, and that by analysis of the risks and benefits of existing activities, the acceptable consensus level is revealed. The application of this approach (Starr 1969), displayed in Figure 1, should be considered primarily useful for illustrative purposes. This figure suggests an acceptability envelope for involuntary public risks, i.e., risks not freely taken and not reasonably avoidable (Starr 1969). Further caveats are in order, for the underlying data from which this was drawn were the actuarial or



*Death rate during exposure to any activity, converted to rate/yr (e g , 1 fatality/d exposure = 365/yr or 1/yr = 1 15 × 10^{-4}/h)

FIGURE 1. Benefit-Risk Pattern of Involuntary Exposure.

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scientific estimates or risk and benefit, when, in fact, the public decisions were based upon public perception of risk and benefit. Further, one does not always know, in an analysis of this type, what alternative technologies and risks were available. This figure is nonetheless intuitively satisfying in that it indicates that an upper limit exists above which public risks are unacceptable regardless of benefit and that a lower limit, or noise level, can be defined. This lower level, corresponding to unavoidable natural risks such as lightning or insect bites, is representative of a regime in which residual risks are likely to be unremovable.

An alternative method to explore the values that underlie risk decisions is the use of expressed preferences, through surveys and other psychological methods. This approach has the advantage that data can be easily gathered, and that perceptions can be measured along with preferences. Further, a central limitation of the revealed preference approach, that "it does not serve to distinguish what is best for society from what is traditionally acceptable" (Starr 1969), is removed. Drawbacks with this approach include the problems of reconciling expressed preference with behavior, and of assessing the strength and stability (Fischhoff et al. 1980) of values. While such expressed preference studies improve our understanding of how people perceive risk and benefit they do not necessarily predict how people will actually respond under real conditions of choice with limited alternatives.

Benefits Precede Risk

It is the perception of potential benefits that stimulates the initiation of the decision-making process on any significant activity, financial investment, or national program. The evaluation of the risks or social costs of proceeding with the action is customarily undertaken only after the perceived benefits warrant further study of the whole matter. Why bother with an analysis of the negative aspects of a concept if there is no interest in its positive values?

Thus, risk analysis presumes that there exist potential negative values which could diminish the potential benefits, and seeks to disclose them and evaluate their importance. By focusing on the disbenefits of a project, risk analysis may provide a touch of cowardice or prudence, depending on your viewpoint. In our culture, where the role model of the bold and successful leader and entrepreneur is generally esteemed, many decision-makers dislike the risk analysis process, denigrate the credibility of its findings, and conveniently avoid, defer, or minimize this negative task where possible. With rare exceptions, it is only when the risks are obvious or perceived as large compared to the benefits that their analysis is undertaken seriously.

Because both benefits and risks of a new activity are likely to be distributed over time and space, and may affect different groups of people, the estimation of future impacts is customarily difficult and incomplete, particularly on a national level. The historical development of our national transportation systems provides excellent examples of all these factors. Their short-term social benefits were initially clearly apparent, but their disbenefits were only dimly perceived and initially considered small on a national scale. As we now know, the railroads, automobiles, and airplanes have massively altered our social structure in ways not foreseen at their initiation, both positively and negatively. (For an interesting view of the predictability of such effects, see Marchetti 1979.) Their benefits clearly accrue to their users, but also indirectly to the nonusers through demographic changes and through strengthening the economy as a whole. Their risks (or social costs) also fall on both users and nonusers in a nonuniform distribution pattern over time and space. What is common to all these transportation systems is that the early entrepreneurs and users enthusiastically foresaw the near-term benefits, and only long after the systems' growth did society recognize many of the disbenefits. And for obvious reasons, these systems have

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gradually become regulated by national agencies as an attempt to belatedly balance the equities among investors, users, transportation workers, and the national interest taken as a whole.

It is thus apparent that national decision-making should be based on a full analytic projection of both benefits and foreseeable risks, performed with equal emphasis and in the same timeframe. Unfortunately, this is rarely the case. More often, federal regulatory bodies concentrate on risks and risk management, while decisions regarding benefit and cost are left to the marketplace and are rarely evaluated. An analysis of the national benefits of any technology or group of technologies is rarely attempted by any regulatory body, except when justification of public expenditures is required (as with military or public works acquisitions). Benefit assessment, as used regarding regulatory decisions, usually refers to the value of risk reductions achieved, and has no relation to the social benefits of the technology. This concentration of regulatory bodies on the negative aspects of technology often has the unfortunate effect of exaggerating their significance relative to the benefits, thus distorting the final decisions.

As an example, for regulation of emissions from coal-fired power plants Congress has a set "zero risk" goal: that air standards be sufficient to protect public health with an adequate safety margin (including risks to sensitive subgroups in the population). With great effort, the EPA adroitly seeks to avoid the impractical solution of setting standards at zero, and control costs are implicitly considered when plans to implement the air quality standards are evaluated (Portney 1978, Lave and Omenn 1981). Things are simpler, at least in theory, for the Nuclear Regulatory Commission (NRC), which is charged with the responsibility to protect the public from "undue" risk. Although the NRC has suggested that nuclear plant risks "should be comparable to or less than the risks of generating electricity by viable competing technologies," (USNRC 1980) no operational plan to base nuclear safety requirements on comparative generation risks has been suggested.

The above approach to coal and nuclear regulation would make sense if the regulatory process merely provided a technological fine tuning of each system to assure that cost-effective safety opportunities had been included. But the effects of regulation go far beyond fine tuning. Regulations or uncertainties regarding future regulation for either coal or nuclear power affect the choice of a generation system by a utility. New requirements or uncertainties regarding requirements surrounding nuclear can cause a shift to coal. Uncertainties in coal effluent requirements lead utilities to burn more oil and gas. Nowhere in this decision process are these options compared on an equivalent basis. No institutional mechanism exists for checking whether the elimination of a nuclear risk produces a larger coal or oil risk. And neither option has its risks compared to the societal benefits of electricity availability at low cost.

In this case, the actual implementing group (i.e., an electric utility) chooses a technology based on the projected direct costs of each option, taking performance uncertainties and the feasibility of plant construction into account. Residual risks are generally ignored except to the extent that their examination is mandated by regulatory requirements. Yet these same residual risks (e.g., acid precipitation, CO2, nuclear accidents) are the focus of great public controversy, concern, and analysis. It is ironic that for pragmatic electricity technology choices, the risk analyses that are the subject of heated public debate play such a minor decision role.

Uncertainty

All projections of future outcomes are based on and limited by the relationships gleaned from past experience. Unfortunately, this body of knowledge is not sufficiently

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comprehensive to provide predictability for all the factors which influence a future outcome. It is customary, therefore, to undertake an analysis of benefits and risks by synthesizing a simplified model of reality, with a limited number of both factors and interactions. Such modeling, whether implicit or explicit, produces projections that are inevitably and obviously uncertain. Any projected trend of events thus becomes more uncertain the longer the time scale, the more it deviates from past experience, and the more new factors are conjectured and included. We start with fuzzy numbers, use a few selected fuzzy relationships, and thus end with fuzzy projections, which become fuzzier still as we go further into the future

On a national basis, epidemiologic surveys reveal gross disease trends, and these may sometimes be related to plausible causative factors. On the individual level, medical practice has a substantial body of lore and science that relate cause, effect, and remedy. But specific outcomes of health decisions are not always predictable. As a historical example, the anticipated swine flu epidemic of 1976, which provoked the Federal Government to institute a preventive inoculation campaign, did not, in fact, occur, and the mass inoculations resulted in rare but serious side effects. The history of this case is typical of the difficulty of national decision-making in health matters: risks are hypothetical, management measures are at the margin of scientific knowledge, and the wisdom of the decision is judged publicly by the outcome.

How then do we handle such uncertainty? In the most general sense, we do so by judgmentally estimating the upper and lower bounds to our outcome. These are the "upside" and "downside" estimates (optimistic and pessimistic, respectively). They are both very subjective, influenced not only by the competence and value judgments of the analyst, but also by the bias, sophistication, and credulity of the decision-maker for whom they are intended.

The key question, then, is how precise need such fuzzy estimates be to provide a useful basis for decision by individuals, groups, or agencies? Clearly, this is an area in which value judgments are inseparably included in risk assessment. How certain is certain enough? The answer may become obvious if net benefits and risks and their distribution are compared for a specific decision. In the simplest case, if the benefits far exceed the risks (including consideration of their estimated upper and lower uncertainty bounds), very rough estimates are good enough for a positive "go" decision. If the risks are estimated to be so large that their mean values are comparable to or greater than the benefits, then unless a gross error has been made, rough estimates are good enough for a "no go" decision. The in-between cases clearly require more care, particularly where the uncertainty bounds of benefits and risks approach or overlap and when benefits and risks are not equitably distributed. It is thus apparent that a simultaneous comparison of benefits and risks is needed in these cases, and the uncertainty boundary may be the determining decision factor. Although uncertainty is inherent in all risk analysis, it need not be a deterrent to decision-making, if benefits and risks are treated alike.

A proper assessment addresses both the risk which accompanies some agent or activity, and the risk that would result from curtailments in its use or from alternatives. A simple example will illustrate this point. Several years ago, chemical studies found that sodium nitrite, a common meat preservative, was metabolized into nitrosamines, chemicals suspected of being carcinogens. After an initial flurry of excitement in which a ban on sodium nitrite seemed likely, it was discovered that many natural food substances form nitrosamines, and that, in fact, the body itself creates them. Next, as the meat industry pointed out, nitrites are effective against spoilage, and particularly against botulism. When it was found that lower levels of nitrite than had historically been used would prevent botulism, such low levels were permitted. The point here is that it is insufficient to consider sodium nitrite risk in isolation, one much also consider

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changes in the risk of botulism and changes in the availability and cost of food to provide a reasonable perspective against which the risk can be considered.

There will be analogous systemic effects for most risks, e.g., if we don't use one energy source we will use other sources (or conservation, which also has risk). But, as pointed out in the previous section, our national regulatory agencies often do not make such comparisons, some are even forbidden by Congress from overtly doing so in health and safety decisions. We then have political criteria for acceptable risk levels usually based solely on concern for individual human life. Under these circumstances, analytic uncertainty of the risk may become a major issue, especially if the risk levels are very low and the empirical basis inadequate, as, for example, with low-level toxicity issues. As Clark notes (1980), procedures are sometimes adopted in such cases in which evidence of risk is sought by multiple means, yet no mechanism exists to provide evidence of safety. The problem is that we are arbitrarily placing a fixed ceiling on a fuzzy low probability risk, whose upper bound is very vague. This has resulted in a variety of regulatory artifices being used in lieu of a national benefit analysis, with resulting distortions of the investment of national resources. Public health and safety have not been cost-effectively optimized. Our political system thus may lead us astray when nobility of purpose in protecting life overrides the common sense observation that we value a complex mix of things, of which freedom from risk is but one component.

Risk Management Approaches

The decision systems in government tend to follow a number of approaches that represent simplifications or approximations to the difficult task of conducting a comprehensive assessment. These approaches encompass criteria from three general areas. First, there are the technical and economic criteria which include estimates of risk and benefit to within plausible ranges of uncertainty, and the distribution of these risks and benefits. Next, for a risk decision process to be practical, the requirements it places on regulators and regulatory institutions must be considered. If the structure is such that the regulator is inescapably exposed to criticism for being arbitrary or biased, the natural reaction of the regulator is to avoid making decisions (as through delay) or to seek simple decision rules that operate openly and mechanistically. The third category of criteria is public input, including both social values and perceptions. These values and perceptions are not fixed points which can be easily measured, but vary from issue to issue and group to group. A major difficulty is distinguishing values from perceptions. This is critical in cases in which a regulator wishes to be sensitive to public values, but to rely on data or expert estimates of risk rather than to base decisions on public perceptions. Most regulatory decision processes are sensitive to all these criteria to some degree.

Under conflict conditions, cost-benefit analysis or decision analysis are merely sideshows; the primary mechanism for balancing costs and benefits is political pragmatism. The administrative agencies which are traditionally responsible for defining the balance of social cost and benefit become the center ring for social policy-making. Over the past decade or more, the actions of these agencies have become subject to intense group pressures and political posturing. Interest groups see in these agencies an opportunity to influence policy by challenging decisions counter to their philosophies. The courts are asked to review agency decisions for detailed consistency with legislation, and Congress, as a final arbiter of political debate, often intervenes in regulating agency actions. Unfortunately, legislation, regulation, and the legal process do not ensure efficient management of health and safety risks.

The existence of conflict conditions is a mixed blessing. On the positive side are the obvious advantages of having critical reviews of the assumptions and analysis upon

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which public decisions are based. Equally important is the openness that comes from public scrutiny of regulatory or policy-making processes. The disadvantages of increasing conflict are primarily operational: decisions are delayed, often for years. Litigation or repeated technical modifications incur costs which would not ordinarily occur. Investment is postponed. For example, by the time the Kaiparowits coal power plant project was cancelled, primarily because of institutional fatigue, 13 years and over $20 million had been consumed in the protracted process of obtaining approvals (Jepperson et al. 1981).

From the viewpoint of the regulated, probably the worst feature of this mode of decision-making is the problem of moving targets; that is, regulatory guidelines are revised at a rate faster than industry can adapt. The viewpoint taken by industry is that it can adjust to a wide range of policies, even those seen as costly, provided the rules are clear and specific, and provided that national policies are predictable for periods roughly comparable to the planning and investment horizons of the industry. In the energy supply sector, these horizons run 20 to 30 years or longer, yet predictions of national energy policy and regulations for even the next several years are speculative.

Understanding Risk Conflicts

As conflicts over technological risk have become more common and more expensive, industry and government have tried to avoid conflicts by understanding the nature of the fear and opposition which some technologies generate. The revealed and expressed preference methods described previously have been helpful in developing a long list of qualities which influence the response to risk and perception of risk (e.g., involuntariness, catastrophic potential, uncertainty, unfamiliarity), and this work has helped explain the fear that many people feel toward nuclear power (Slovic et al. 1980). The research on risk perception has produced many insights into the way people estimate risk, but there is still much to understand. For example, based on its potential risk characteristics, one would have expected recombinant DNA research to have provoked far more controversy and opposition than it has.

Perceived risk is the best understood element of how people respond to technological risk. We do not understand perceived benefit, value systems, and decision rules to nearly the same degree. Not surprisingly, our understanding is most solid when generalizations are valid, that is, when everyone responds consistently and in the same way. When people or groups are in conflict, these research methods are less useful.

Much of the work to understand such conflicts has focused on social interactions rather than the quantitative significance of the risk. For example, Dorothy Nelkin (1980) has focused on the degree to which the decision process allows public participation, and has described conditions for such participation as:

> "... due weight to social and political concerns, the appropriate involvement of affected interests, an unbiased management, a fair distribution of expertise, and a real margin of choice ... these conditions are not likely to produce consensus, but they may reduce mistrust and hostility towards political and administrative institutions."

While this advice may be helpful, it doesn't explain, for example, how the FAA, which regulates aircraft safety through a close cooperative relationship with aircraft manufacturers and airlines, has escaped the conflicts which surround Nuclear Regulatory Commission decisions, despite the NRC's more open decision process and less cozy relation with the industry it regulates.

A far more ambitious explanation for risk conflicts has been offered by Douglas and Wildavsky (1982), who propose that risks are selected by concerned groups in large part because a large external threat provides cohesiveness to otherwise unstable

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sectarian groups. They suggest that selection of these threats are culturally determined, but leave unanswered the critical questions of how one explains profound concern over risk by mainstream groups, and why one becomes a sectarian.

While it is tempting to consider risk controversies as a recent phenomenon, with origins in the environmental awareness that arose in the 1960's, there is a much longer trend in public concern with safety.

As we examine the longer-term attitudes of humanity toward risk and the individual's rights to safety (see Hammer 1980 for an excellent summary), we are struck by the fact that the trend to public concern did not begin with *Silent Spring*. Hammer observes that from biblical times to the Industrial Revolution, the social view of risk changed from strict liability for injury (i.e., liability even for unintentional damage done without fault or negligence) as in the "An eye for an eye" ethic, to the Industrial Revolution in which "the government, the courts, and the industrialists were willing to compromise safety for economic advantage (Hammer 1980)." Individual rights reached low ebb in 19th century England, in which recovery for damage required a contractual arrangement between plaintiff and defendant, and proof of negligence or fault as well. But since this time, individual rights have made a strong comeback, signaled in recent years by the Occupational Safety and Health Act (1970), the Consumer Product Safety Acts (1972), and many other laws and court decisions. While to the economist the risk issue may involve the balance of appropriate factors, to the politician sensitive to current public concerns, freedom from technological risk is a right, without regard to the infeasibility of zero risk.

Summary

We have tried in a short space to describe the special nature of health and safety risk decisions, and to indicate how these issues differ from financial decisions under uncertainty. For many of these health issues, the risk uncertainty, while inherent, is not the essence of the problem. Often the principal difficulty is interpretation of conflicting and diffuse objectives for risk decisions, as they are expressed through the political process. The central concern is frequently with the equity of risk distribution, rather than with comparisons of risk and other costs with benefit. When such problems are approached analytically, the critical step is the choice of social values, rather than the numerical details of analysis.

Perhaps the most important role for risk analysis within the current risk management framework is to identify decisions which imply highly unusual value systems. In these cases, analysis leads to a wider disclosure of both assumptions and criteria, and helps focus the public debate. It is instructive to recall that the systematic use of cost-benefit analysis arose from conservationists' objections to many projects carried out in water resource management by the Corps of Engineers; in these cases analysis was used to check an apparent bias to overbuild. During the 1970's, business groups undertook risk analysis in response to a perceived bias in government against business interests. Used carefully, risk analysis can stabilize and lend predictability to the complex process for arriving at regulatory decisions, and provide for a wider disclosure of the mechanisms of the decision process at the same time.

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